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RESEARCH ARTICLE

Distribution and conservation of vanilla crop wild relatives: the value of local community engagement for biodiversity research

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Abstract

Natural vanilla is a high-value crop with demand increasing globally. Crop wild relatives (CWR) represent valuable agrobiodiversity and are prioritized in the Global Strategy for Plant Conservation. *Vanilla* species are naturally rare with historically infrequent botanical collections. Despite their importance as CWR, fewer than 10% of *Vanilla* species have been evaluated for the IUCN Red List. Colombia is a diversity center for *Vanilla* species, yet many remote regions are lacking detailed floristic characterization. We show that the participation of rural communities in scientific endeavor enhances capacity to register biodiversity. We report two *Vanilla* species in the under-explored region of the Serranía de las Quinchas in the mid–Magdalena River valley in Colombia, including the first report for Colombia of *Vanilla karen-christianae*. For this, and the second species, *Vanilla dressleri*, we present descriptions with photographic botanical illustrations, updated distribution maps, and preliminary conservation status assessment. Both species are of elevated conservation concern, categorized as Endangered – EN: B2a,b(ii,iii,iv,v) following IUCN criteria. Within Colombia, all recorded occurrences for both species fall outside protected areas. Vanilla crop wild relatives in Colombia have urgent conservation needs. The Serranía de las Quinchas is a priority for further botanical exploration for *Vanilla*, as well as other protected areas with appropriate habitat. *In situ* conservation should be complemented with *ex situ* actions. Community participation in biodiversity research is recommended in this and other remote regions as an integral step towards enhancing biodiversity research and community-based conservation.

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PENSOFT

Keywords
citizen science, Colombia, community-based participatory research, natural rarity, Red List, Serranía de las Quinchas, Tumbes–Chocó–Magdalena biodiversity hotspot, *Vanilla dressleri*, *Vanilla karen-christianae*

Introduction

Crop wild relatives (CWR) are broadly defined as undomesticated plant taxa closely related to species of socio-economic value, including crops, medicinal plants, condiments, as well as ornamental and forestry species. CWR are widely recognized as vital resources for promoting global food security and sustainable rural livelihoods in the face of climate change (Hajjar and Hodgkin 2007; Dempewolf et al. 2014; Kersey et al. 2020; Ulian et al. 2020). As such, CWR are essential to achieve the Sustainable Development Goals 2 (Zero Hunger) and 12 (Sustainable consumption & production patterns) (UNDP 2022). Accordingly, CWR were prioritized for conservation action in the Aichi Biodiversity Target 13 (Convention on Biological Diversity, CBD 2020) and Target 9 of the Global Strategy for Plant Conservation (CBD 2011). This prioritization continues in the post-2020 Global Biodiversity Framework, to ensure the conservation and management of socio-economically important wild plants *in situ* and *ex situ* (CBD 2022).

Like all wild plant species, CWR are increasingly threatened by anthropogenic activities including unsustainable agro-environmental management, habitat transformation and climate change (Heywood et al. 2007; Maxted et al. 2010). As components of agrobiodiversity, conservation actions for CWR have mainly focused on genetic diversity collection and maintenance *ex situ*, primarily as a means of enhancing CWR availability for crop breeding. However, despite their importance, CWR diversity is still poorly represented in gene banks (Castañeda-Álvarez et al. 2016). In addition to *ex situ* conservation actions, the *in situ* conservation of these wild species must also be prioritized to ensure the maintenance of their evolutionary potential (Meilleur and Hodgkin 2004) as well as essential ecological interactions, including the symbiotic microbiome (Murphy et al. 2019). An important preliminary step for both *in situ* and *ex situ* conservation actions for CWR is to ensure a clear understanding of species taxonomy and distributions.

Natural vanilla is the second most economically valuable spice crop. With its high value, the vanilla crop has potential for promoting rural development across tropical and sub-tropical regions (Flanagan and Mosquera-Espinosa 2016; Havkin-Frenkel and Belanger 2018) yet is historically understudied. Phytosanitary problems have risen in parallel with the expansion of cultivation (e.g. Xiong et al. 2015; Havkin-Frenkel and Belanger 2018), and crop improvement programs are urgently needed. The wild relatives of the cultivated species *Vanilla planifolia* offer resources for diversifying the genetic base of natural vanilla cultivation (Maruenda et al. 2013; Flanagan et al. 2018; Nascimento et al. 2019; Pérez-Silva et al. 2021; da Silva Oliveira et al. 2022), however, more research is needed in the exploration of these crop wild relatives.

The genus *Vanilla* Plum. ex Mill. (Orchidaceae) has a pan-tropical distribution and includes approximately 120 hemiepiphytic to epiphytic species (Soto Arenas and

Cribb 2010). The secondary gene pool of the crop (*Vanilla* subgenus *Xanata* Section *Xanata* Soto Arenas and Cribb 2010) comprises more than 40 species, naturally distributed within the neo-tropical region. While *Vanilla* species frequently have broad distributions (Soto Arenas and Cribb 2010; Soto Arenas and Dressler 2010; Karremans et al. 2020), they may often be locally very rare (e.g. Ferreira et al. 2017; Barona-Colmenares 2018; Engels et al. 2020). This natural rarity explains the scarce representation of *Vanilla* in biological collections and has historically been an obstacle to taxonomic studies in this genus. With a recent increase in attention to *Vanilla* taxonomy, several species have been described in the last decade, the majority with very restricted known distributions (Soto Arenas 2010; Soto Arenas and Dressler 2010; Koch et al. 2013; Molineros-Hurtado et al. 2014; Pansarin and Miranda 2016; de Fraga et al. 2017; Barona-Colmenares 2018; Karremans and Lehmann 2018).

Despite the conservation prioritization of crop wild relatives, only nine *Vanilla* species within the Section *Xanata* (11 in total for the genus) have been evaluated for the IUCN Red List of Threatened Species (IUCN, 2022). Of these nine, one, *V. cribbiana* is considered critically endangered, seven are classified as endangered, with one Data Deficient. The conservation status evaluation of all *Vanilla* species, and particularly those within the Section *Xanata*, as valuable crop wild relatives, is urgently required.

Colombia is at the center of distribution for the Section *Xanata*, yet to date no conservation status evaluations have been undertaken for *Vanilla* species in this country. Recent work has documented 26 *Vanilla* species for the country, of which 21 belong to the Section *Xanata* (Flanagan et al. 2018; Barona-Colmenares et al. 2019). Both historical herbaria data, and recent fieldwork indicate that these species distributions may be highly disjunct, more so due to habitat fragmentation in the last century. Nonetheless, many regions in Colombia are botanically underexplored (Arbeláez-Cortés 2013), and while our understanding of *Vanilla* species distributions is increasing, much more work is needed.

The Andean foothills of the Serranía de Las Quinchas cover 860 km^2 of rugged terrain between 200 and 1,700 m. a. s. l. on the Western slope of the Eastern Cordillera of the Andes in Colombia, in the mid–Magdalena River valley. This region is at the eastern edge of the Tumbes–Chocó–Magdalena Biodiversity Hotspot (Mittermeier et al. 2011), which ranges from the mid–Magdalena River valley, across northwest Colombia, and down the pacific coast of Colombia and Ecuador to northern Peru. Although forest cover was once continuous to the Darién region to the northwest and into Central America, the natural ecosystems of the Magdalena River valley have been highly fragmented by expanding cattle ranches and palm oil plantations (Mayaux et al. 2005). The Serranía de las Quinchas is now one of the last remnants of humid tropical forest in the mid watershed of the Magdalena River valley (Etter et al. 2006).

The Serranía de las Quinchas has been recognized as an Important Bird Area, requiring focused habitat conservation strategies (Laverde Rodríguez et al. 2005). A floristic survey undertaken two decades ago registered significant diversity, with 1036 species belonging to 496 genera in 118 families (Balcázar-Vargas et al. 2000). Nonetheless, the region has been neglected in terms of biodiversity studies. Recently,

however, several new orchid species have been described in neighbouring, higher altitude regions (Gutiérrez-Morales et al. 2018, 2021; Hágsater et al. 2018).

To ensure success, conservation research and management approaches must effectively engage local communities, as well as ensuring their livelihood needs are adequately met (Bajracharya et al. 2006; Lentijo et al. 2008). Citizen science, defined as the engagement of non-professionals in authentic scientific research (Dickinson et al. 2012), combines robust capacity-building experiences with enhanced power to further scientific research objectives. In Colombia, a mega biodiverse country, a study in coffee growing areas in the Andes found that farmers believed that a lack of environmental awareness and lack of knowledge were the main barriers to practices to promote bird conservation (Lentijo and Hostetler 2013). Community-based participatory research strategies facilitate the construction of knowledge systems that integrate both scientific and empirical perspectives. Such an inclusive approach with indigenous people & local communities (IPLC) promotes dialogue and knowledge exchange and has a key role in local biodiversity research and management strategies, by strengthening effective ties with biodiversity, and promoting awareness among local communities and thereby actions in favour of the conservation and sustainable use of biodiversity (Soacha-Godoy and Gómez 2016; IPBES 2019).

Through participatory research practice involving local community members (ENG-P and HM-M) in the Municipality of Otanche, Boyacá, Colombia and scientists (NSF and AN-S), we here report two *Vanilla* species in the Serranía de las Quinchas, including the first report in Colombia of the species *Vanilla karen-christianae* Karremans and P.Lehm., 2018 (Orchidaceae, Vanilloideae). With these new reports we provide updated distributions, contribute additional details to the species descriptions and provide the first evaluations of conservation status following IUCN criteria for these species. We also provide recommendations for conservation of these species at the national level in Colombia.

Methods

Study site and specimens

The vanilla plants were found in the Municipality of Otanche, Department of Boyacá, Colombia. The locality falls within the buffer zone of the Regional Forest Reserve Las Quinchas. Sub-Andean tropical life zones are present under 1,000 m elevation, where pastures and agricultural areas form a mosaic with small relicts of tropical humid forest. The average temperature is 24–26 °C, with average annual precipitation of 2500–3000 mm (IDEAM 2022).

The local community members (ENG-P and HM-M) discovered *Vanilla* vines during routine activities on their agricultural smallholdings in the villages of Altazor and San José de Nazareth, and made contact with researchers through the online platform https://www.inaturalist.org.

The plants of *Vanilla dressleri* were monitored by ENG-P until flowering. At the time of detection, the *V. karen-christianae* individual had several inflorescences. Flowers were collected, dissected, and photographed in the field, and plant morphological measurements taken from live material. Composite photographic plates were prepared using Adobe Photoshop v. 21.0.3, with light and brightness correction in Adobe Photoshop Lightroom Classic v. 9.0 (Adobe Systems Incorporated). Floral parts were measured using the program ImageJ bundled with Java 1.8.0_172 (Schneider et al. 2012). Species identification was achieved following Soto Arenas and Cribb (2010), Soto Arenas and Dressler (2010) and Karremans and Lehmann (2018).

Species distributions

We compiled a dataset of all occurrence records for both *Vanilla karen-christianae* and *V. dressleri* from sources including Soto Arenas and Dressler (2010), Karremans et al. (2020), Karremans and Lehmann (2018), Rojas-Álvarez (2020), Rodríguez-Salamanca (2020), Navia-Samboni (2021) and the new records from this study. In addition, online databases and herbaria were searched, including GBIF (https://www.gbif.org), TROPICOS (https://www.tropicos.org), SiB (https://sibcolombia.net) and iNaturalist (https://www.inaturalist.org). Based on the records found, three maps were constructed in ArcGIS Pro 2.8.0 (https://www.esri.com/): the global distribution of *Vanilla karen-christianae* and of *Vanilla dressleri*, and the distribution of both species in Colombia. Distinct shape files were used for each country, including layers for elevation, political boundaries, and rivers (https://www.diva-gis.org), protected areas (https://www.protectedplanet.net), the Tumbes–Chocó–Magdalena hotspot and presence of humid tropical forest (https://globalforestwatch.org) [All websites accessed April–July 2021], with the application of a final layer with the coordinates of the occurrences for the species studied (Tables 1 and 2).

Conservation status

We evaluated the conservation risk status of *Vanilla karen-christianae* and *V. dressleri* according to the IUCN Guidelines for Using the IUCN Red List Categories and Criteria version 15 (IUCN Standards and Petitions Committee 2022). The Extent of Occurrence (EOO) and Area of Occupancy (AOO) of each species were calculated with GeoCAT (http://geocat.kew.org). The EOO value obtained is a clear overestimation, as the polygon includes marine areas as well as habitats at higher elevation, where these species do not occur. To approach a more precise value for EOO, the terrestrial areas below 1500 m.a.s.l. within the minimal convex polygon were calculated in ArcGIS Pro, version 2.8.0 (https://www.esri.com/). Nonetheless, this value still does not consider the contemporary prevalence of suitable humid tropical forest habitat, and so the area of humid tropical forest remaining within the polygon was also calculated.

Table 1. Global records of *Vanilla karen-christianae*. Herbariums: MO (Missouri Botanical Garden); SEL (Marie Selby Botanical Gardens); USM (Herbarium Hattiesburg, The University of Southern Mississippi); JBL-Spirit (Jardín Botánico Lankester, Universidad de Costa Rica); MOL (Herbarium Weberbauer, Universidad Nacional Agraria La Molina); CEN (Embrapa Recursos Genéticos e Biotecnologia); MG (Museu Paraense Emílio Goeldi); N/A - Not Available.

Record No.	Coordinates (Latitude, Longitude)	Country	State or Province	Locality	Elevation (m.a.s.l)	Collector	Record Year	Records herbarium	Source
1	13.700027, -84.573888	Nicaragua	Matagalpa	Cerro Kana Coperna	250	D. Neill	1978	MO 457	TROPICOS, GBIF, Karremans et al. (2020)
2	13.65, -84.808333	Nicaragua	Matagalpa	Cerro Waylawás	100–270	W. Stevens	1978	MO 7385	TROPICOS, GBIF
3	13.058, -85.72	Nicaragua	Matagalpa	La Dalia, Cerro Waylawás	250	D. Neill	1978	SEL - MO 4219	GBIF, Karremans et al. (2020)
4	12.740750, -85.437972	Nicaragua	Matagalpa	Siuna, Río Matis	<100	F. Ortiz	1982	MO 172	Karremans et al. (2020)
5	11.006339, -84.962492	Nicaragua	Río San Juan	Refugio los Guatuzos	30	E. van den Berghe	2021	Photograph by van den Berghe	iNaturalist
6	10.130094, -83.604406	Costa Rica	Limón	Siquirres, Germania	250	A. Karremans	2020	JBL Spirit 8356	Karremans et al. (2020)
7	8.538000, -82.850528	Costa Rica	Puntarenas	Corredores, Canoas	130	A. Karremans	2017	JBL Spirit 8123	GBIF, Karremans et al. (2020)
8	8.577222, -82.873056	Costa Rica	Puntarenas	Corredores, Canoas	130	A. Karremans et al.	2017	USJ - JBL Spirit - MO 8087	GBIF, Karremans et al. (2020)
9	5.8090, -74.1139	Colombia	Boyacá	San José de Nazareth, Otanche	770	This study	2020	Fig. 1; This study	This study
10	-1.578667, -55.685250	Brasil	Pará	Río Branco de Óbidos	N/A	A. Goeldi	1927	N/A	TROPICOS
11	-7.340667, -66.415722	Brasil	Amazonas	Río Purús	N/A	J. Huber	1904	MG-007302 s.n.	TROPICOS
12	-9.416028, -64.698972	Brasil	Rondonia	Cachoeira de Jirau	90	G. Pereira-Silva et al.	2010	CEN-00078538 15128	TROPICOS
13	-6.454639, -76.656917	Peru	San Martín	N/A	400	R. Ferreyra, Rauh and Bismarck	1973	USM 18265	Karremans et al. (2020)
14	-6.951028, -76.350222	Peru	San Martín	Puerto Rico	200	A. Damián and M. León	2018	USM 906	Karremans et al. (2020)
15	-9.131972, -74.496500	Peru	Ucayali	Reserva Comunal el Sira	180	J. Janovec, J. Ushinawa and H. Behar	2015	MOL 4006, 4009	Karremans et al. (2020)
16	-10.838556, -75.289750	Peru	Junín	Puente Paucartambo	200	D. Aliaga	2018	USM s.n.	Karremans et al. (2020)
17	-11.102, -75.349917	Peru	Junín	Chanchamayo Fundo la Genova	1100	A. Damián and Botanic's students UCSUR	2016	USM 905	Karremans et al. (2020)
18	-12.256611, -70.898	Peru	Madre de Dios	Boca Manú	280–320	J. Householder, A. Balarezo and J. Huinga	N/A	USM 941	Karremans et al. (2020)
19	-12.599306, -69.052944	Peru	Madre de Dios	Sandoval, Lago Sandoval	150	N/A	N/A	No Voucher	GBIF
20	-12.695000, -69.469306	Peru	Madre de Dios	Comunidad Mercedes	200–250	J. Householder, A. Balarezo and J. Huinga	2007	USM 14	Karremans et al. (2020)
21	-12.487097, -68.95488	Peru	Madre de Dios	Concesión Inkaterra	180	M.A. Rodríguez-Salamanca	2020	Photograph by Rodriguez-Salamanca	Rodríguez-Salamanca (2020)
22	-12.479953, -68.954190	Peru	Madre de Dios	Concesión Inkaterra	150	M.A. Rodríguez-Salamanca	2020	Photograph by Rodriguez-Salamanca	Rodríguez-Salamanca (2020)

Table 2. Global records of *Vanilla dressleri*. Herbariums: MO (Missouri Botanical Garden); INBio (Herbario del Insituto Nacional de Biodiversidad de Costa Rica); CUVC (Herbario Luis Sigifredo Espinal Tascón, Universidad del Valle); QCNE (Museo Ecuatoriano de Ciencias Naturales); N/A - Not Available.

Record No.	Coordinates (Latitude, Longitude)	Country	State or Province	Locality	Elevation (m.a.s.l.)	Collector	Record Year	Records for herbarium	Source
1	10.978611, -85.11	Costa Rica	Alajuela	San José de Upala	40	Gerardo Herrera	1988	MO 1840	TROPICOS, GBIF
2	10.333333, -84.716666	Costa Rica	Alajuela	Reserva Monteverde	820	William Haber and Eladio Cruz	1987	INBio - MO 7243	TROPICOS, GBIF
3	10.316666, -84.716666	Costa Rica	Alajuela	Reserva Monteverde	900	William Haber and Eladio Cruz	1988	INBio - MO 8471	TROPICOS, GBIF
4	9.8, -83.7	Costa Rica	Cartago	Jiménez	700	Ronald Liesner	1983	MO 14435	TROPICOS, GBIF
5	9.446388, -83.987222	Costa Rica	Puntarenas	Rafiki Safari, Aguirre	250	Joaquín Sánchez González	2002	MO 1219	TROPICOS, GBIF
6	9.67, -83.02	Costa Rica	Limón	Reserva Hitoy Cerere	400	Gerardo Carballo	1990	INBio - MO 325	TROPICOS, GBIF
7	8.671611, -83.567666	Costa Rica	Puntarenas	Rancho Quemado	100	N/A	1990	No Voucher	GBIF
8	8.7666666, -83.25	Costa Rica	Puntarenas	Parque Natural Piedras Blancas	100	Marianela Segura	1993	MO 121	TROPICOS, GBIF
9	9.201666, -79.84444	Panama	Canal Área	Península Bohío	40	Sandi Knapp and Jim Mallet	1982	MO 4621	TROPICOS, GBIF
10	9.4, -79.65	Panama	Colón	Parque Natural Chagres	550	Gordon McPherson	1986	MO 9196	TROPICOS, GBIF
11	6.333333, -77.333333	Colombia	Chocó	Playa Huaca, Bahía Solano	100	Felipe García-Cossio, and Enzo Agualimpia	1990	MO 325	TROPICOS, GBIF, SiB
12	6.177694, -77.387944	Colombia	Chocó	El Cedro, Bahía Solano	40	Nicola Flanagan and Andres Navia-Samboni	2020	Photograph by N. Flanagan	Navia-Samboni (2021)
13	6.182697, -77.393739	Colombia	Chocó	El Cedro, Bahía Solano	40	Camilo Rojas Álvarez	2020	No Voucher	Rojas-Álvarez (2020)
14	6.161027, -77.371222	Colombia	Chocó	El Cedro, Bahía Solano	100	Sean Higgins	2017	Photograph by S. Higgins	iNaturalist, GBIF
15	6.150000, -77.350897	Colombia	Chocó	Río Valle, Bahía Solano	20	Camilo Rojas Álvarez	2020	No Voucher	Rojas-Álvarez (2020)
16	6.078699, -77.330135	Colombia	Chocó	El Cedro, Bahía Solano	50	Camilo Rojas Álvarez	2020	No Voucher	Rojas-Álvarez (2020)
17	6.033333, -75.133333	Colombia	Antioquia	La Piñuela, Cocorná	830	Diego Giraldo Cañas	1993	HUA - MO 1731	GBIF
18	5.8247, -74.1303	Colombia	Boyacá	Altazor, Otanche	400–950	This study	2020	Fig. 2; This study.	This study
19	4.071277, -77.087861	Colombia	Valle del Cauca	La Trojita, Río Calima	30	José Cuatrecasas	1944	CUVC - MO 16650	TROPICOS, GBIF, Soto Arenas and Dressler (2010)
20	3.630916, -76.928166	Colombia	Valle del Cauca	Anchicaya	270	José Cuatrecasas	1943	No Voucher	GBIF, Soto Arenas and Dressler (2010)
21	0.933333, -78.6	Ecuador	Esmeraldas	Alto Tambo	250	Daniel Rubio, Carlos Quelal and Cleto Pai	1991	QCNE - MO 1131	TROPICOS, GBIF

Results

We report the first record of the species *Vanilla karen-christianae* Karremans & P.Lehm. (Figs 1, 3A) in Colombia, as well as a new report for *V. dressleri* Soto Arenas (Figs 2, 3B), both in the Serranía de las Quinchas, Department of Boyacá, Colombia.

Vanilla karen-christianae **Karremans & P.Lehm. Orchids (West Palm Beach) 87(4): 305 (2018).**

Type. Costa Rica. Puntarenas: Corredores. Canoas, 27 Sept. 2017, A.P. Karremans et al. 8087 (holotype: USJ; isotypes: JBL-spirit, CR).

New record. *Vanilla karen-christianae* Colombia. Boyacá Department, Municipality of Otanche; coordinates: 5.8090, -74.1139; 400 m.a.s.l.; 11 Oct. 2020; NS Flanagan et al. (Figs 1, 3A).

Hemiepiphytic, scandent vine, up to 20 m long. ***Stems*** flexuous, sulcate, ca. 4–10 mm thick; internodes, 6.5–16.5 cm long. Aerial ***roots*** attaching, flattened 1.0–3.7 mm wide. ***Leaves*** alternate, coriaceous, petiolate, the petiole canaliculate, 5.5–11.0 mm long, ca. 3 mm wide; blade linear to sub-lanceolate, acuminate, conspicuously recurved at apex, 11–17.5 × 1.8–3.5 cm. ***Inflorescence*** 1–8 per plant, axillar, up to +30 flowers per raceme; rachis ca. 9 cm long, congested. ***Floral bracts*** sheathing, ovate, concave ca. 5–6 mm long. ***Flowers*** successively 1 to 2 days apart, one open at a time, ephemeral, segments not spreading, ovary basal half white, apical half green, sepals and petals light green, shiny, lip white to cream with the side veins and appendages cream to pale yellow, penicillate callus white, column white and appendages cream to pale yellow. ***Ovary*** subterete, smooth, arcuate, 30–35 mm long, 3–4 mm thick. ***Dorsal sepal*** oblanceolate, apex acute 41–55 × 10–14 mm. ***Lateral sepals*** broadly oblanceolate, apex acute, 46–55 × 14–19 mm. ***Petals*** obliquely linear to lanceolate, apex acute, with a conspicuous, elevated, longitudinal keel on abaxial surface; 42–51 × 7–14 mm. ***Lip*** fused to the column along the margins for ca. 2.5 cm, tubular, concave, inflated near the middle, becoming deeply saccate; axially grooved on the abaxial surface; the apex deeply emarginate, with or without a recurved tip; when spread out 48–50 × 41–47mm; conspicuously trilobed; central lobe cuadrate, bilobed, margins crenulate, strongly undulate, ca. 16–veined, the veins thickened forming low, papillose keels, trichomes taller towards the apex, 20–27 × 15–18 mm; lateral lobes subrhombic, obtuse, margins entire, sub-undulate; ***penicillate callus*** retrorse, 30–35 mm from the base, 9–10 obdeltate to cuadrate, scales with sinuate distal edge, progressively smaller from apex 4–7 × 2–5 mm. ***Column*** subterete, ventrally flattened, 25–30 × 4–6mm; densely pilose on apical ¾ of ventral surface, with trichomes of increasing length apically. ***Stigma*** trilobed, lateral lobes erect, oblong, margin subcrenate, rostellum, transversely oblong 4.5 × 2.5 mm. ***Anther*** versatile, 3.4 × 4.8mm. ***Pollen*** 2 cuadrate, bilobed granular masses. ***Fruit*** sub–trigonous 6.5× 1.6 cm immature, lightly fragrant.

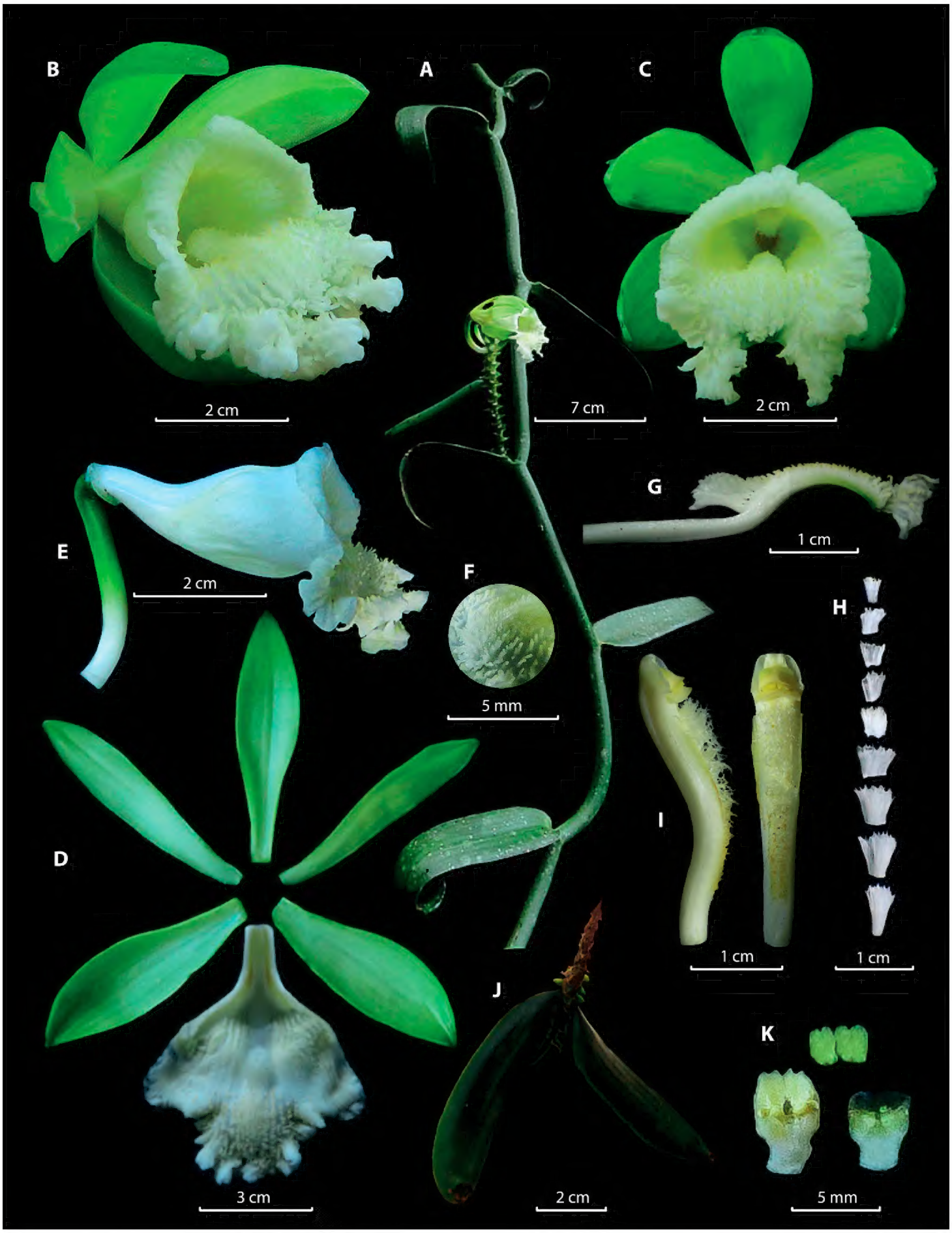


Figure 1. *Vanilla karen-christianae* from the Serranía de las Quinchas, Boyacá, Colombia. **A.** Habit **B** and **C.** Two separate flowers viewed from different perspectives **D.** Dissected perianth **E.** Lip and ovary lateral view **F.** surface of the central lobe of the labellum showing abundant trichomes **G.** Longitudinal dissection of the labellum, with the apex to the right, showing the retrorse position and form of the penicillate callus **H.** Individual combs of the penicillate callus **I.** Column, ventral and lateral view **J.** Fruit **K.** Anther cap and pollinia.

Vanilla karen-christianae can be distinguished from other species present in Colombia with similar narrow leaves, *V. odorata* and *V. phaeantha*. Leaves of *V. odorata* are more petiolate, while those of the latter are equally or more sessile, and more linear-oblong. Both lack the recurved apex on the leaf. In the flower, the lip of *V. karen-christianae* is strikingly adorned, compared to both similar species: *V. odorata* has an entire lip, with a minimally papillose surface; *V. phaeantha* has a less congested rachis, a somewhat trilobed lip, conspicuously unguiculate, with only two rows of trichomes. This record of *V. karen-christianae* differs from the type description in having larger dimensions in the flower, with less intense coloration. Notably, the lip of this new record is conspicuously trilobed, compared with obscurely trilobed in the type specimen. The penicillate callus comprises 9 or 10 scales.

A single plant of *Vanilla karen-christianae* was found on the agricultural smallholding, La Esperanza, belonging to Hernan Mendieta-Matallana in the village of San José de Nazareth. The vines of this plant cover an area of approximately 20 m^2 either side of a footpath. This site presents disturbed secondary forest cover. The specimen had several inflorescences on discovery, and subsequent monitoring revealed that flowering occurs during the months of August and October.

Vanilla karen-christianae, described in 2018 (Karremans and Lehmann 2018), has a total of 22 occurrence records globally from 19 localities, with an altitude distribution between 30 and 1100 m.a.s.l. This species has a highly disjunct distribution, with occurrences in Central America, from northern Nicaragua, through Costa Rica and Panama, as well as across the Amazon basin from Madre de Diós, Peru to Pará, Brazil (Table 1; Fig. 4A). Our new report for this species in Colombia provides a connection between these disjunct distributions in Mesoamerica and the Amazon basin.

The total Extent of Occurrence (EOO) for this species calculated with GeoCAT was 4,447,442 km^2. When only terrestrial areas below 1,500 m.a.s.l. were considered, this was reduced to 3,488,798 km^2. Within this area 2,484,296 km^2 corresponds to humid tropical forest, of which 421,222 km^2 occurs in Colombia. The Area of Occupancy (AOO) calculated for this species is 88 km^2.

***Vanilla dressleri* Soto Arenas. Lankesteriana 9: 303–305 (2010).**

Type. Panama, Colón: End of Pipeline Road, Gamboa, 15 April 1982, S. Knapp 4621 & J. Mallet (holotype: MO 3032952).

New record. *Vanilla dressleri* Colombia. Boyacá Department, Municipality of Otanche; Vereda Altazor. Coordinates: 5.8247, -74.1303; 770 m a.s.l.; 11 Oct. 2020; NS Flanagan et al. (Figs 2, 3B).

Hemiepiphyte, scandent vine, poorly branching, up to 20 m long. ***Stems*** flexuous, terete, 4.0–6.4 mm thick; internodes 3.0–16.5 cm long. Aerial ***roots*** attaching, flattened 0.6–2.8 mm thick. ***Leaves*** alternate, petiolate, the petiole canaliculate, 7–18 mm long, ca. 4 mm wide; blade entire, variable lanceolate to ovate–elliptic, shortly acuminate–cuspidate, with a conspicuous central axial canal on adaxial surface, fleshy, pendant to spreading, commonly larger than the internodes 11.5–18.3 × 3.7–5.5 cm.

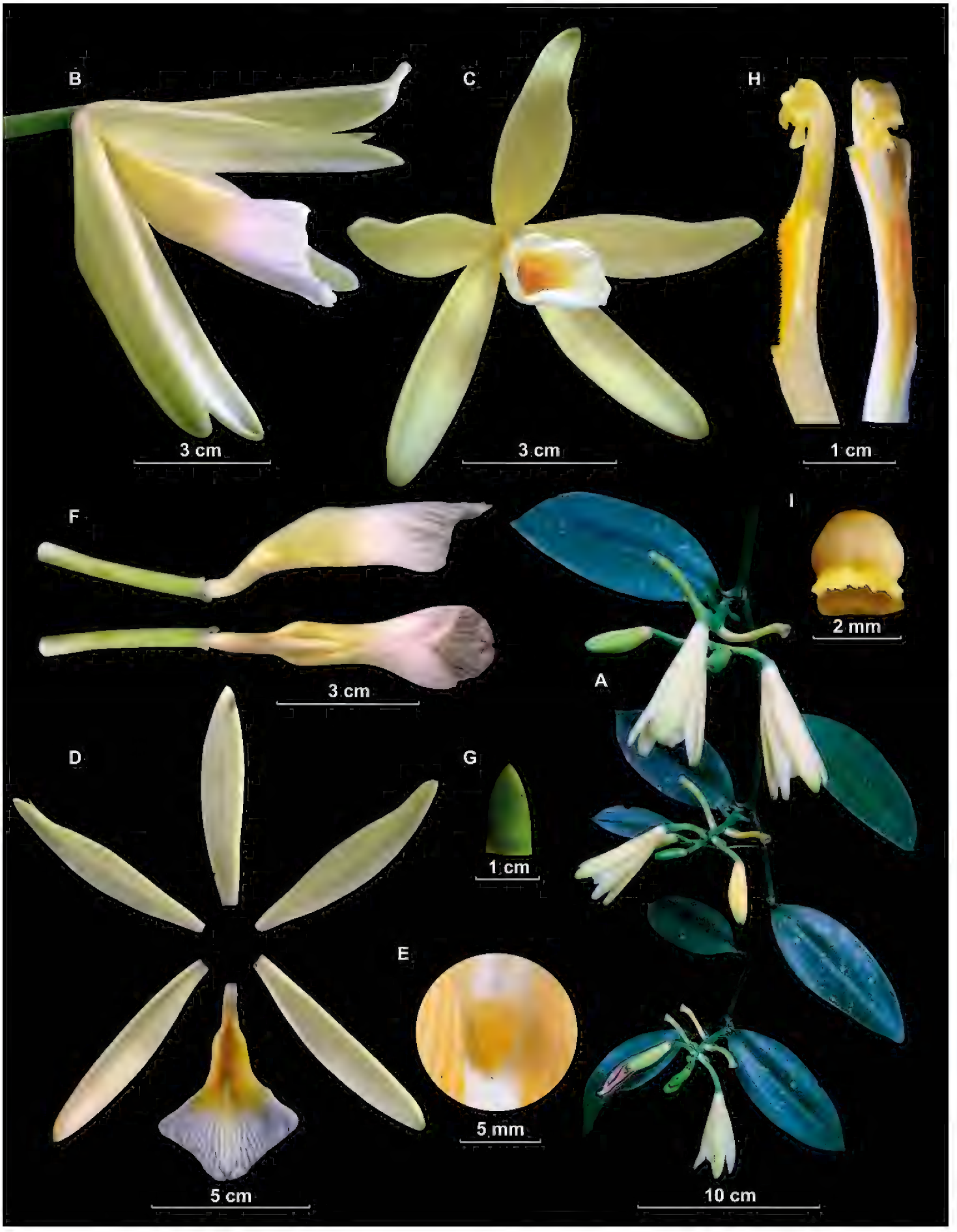


Figure 2. *Vanilla dressleri* from the Serranía de las Quinchas, Boyacá, Colombia. **A.** Habit **B** and **C.** Two separate flowers viewed from different perspectives **D.** Dissected perianth **E.** Penicillate callus **F.** Lip and ovary lateral and dorsal view **G.** Flower bract **H.** Column, ventral and lateral view **I.** Anther cap.

Inflorescence ca. 12 per plant, axillar, racemose, a 3–13 flowered raceme, lax, bracts distant up to 20 mm, rachis up to 75 mm long. ***Floral bracts*** sheathing to spreading, obtusely deltate-ovate, concave, 7–8 × 13–19 mm; ***Flowers open*** successively 3 to 6 days apart, 1 to 3 open at a time, ephemeral, big and showy, tepals pendant to

spreading, cream to greenish–yellow on outer surface, lip orange yellow on basal 2/3 of the inner surface, fading to white towards the apex, orange color more intense on the elevated veins, column white basally, with yellow apex; fragrance principally on sepals also petals, mentholate. ***Ovary*** subterete, greenish–white, straight to curved, thickened towards the base, 35–37 mm long, 4–5 mm thick; calyculate. ***Dorsal sepal*** narrowly elliptic, apex broadly acute, subcalyptrate, base canaliculate, 67–79 × 13–14 mm. ***Lateral sepals*** narrowly elliptic, apex broadly acute–rounded, calyptrate, base canaliculate, 69–75 × 11–13 mm. ***Petals*** narrowly elliptic, apex broadly acute–rounded, calyptrate, basally canaliculate, with a conspicuous elevated, longitudinal keel on abaxial surface; 69–75 × 11–15 mm. ***Lip*** attached to the column along the margins of the basal two thirds (ca. 25 mm), tubular, concave, axially grooved on

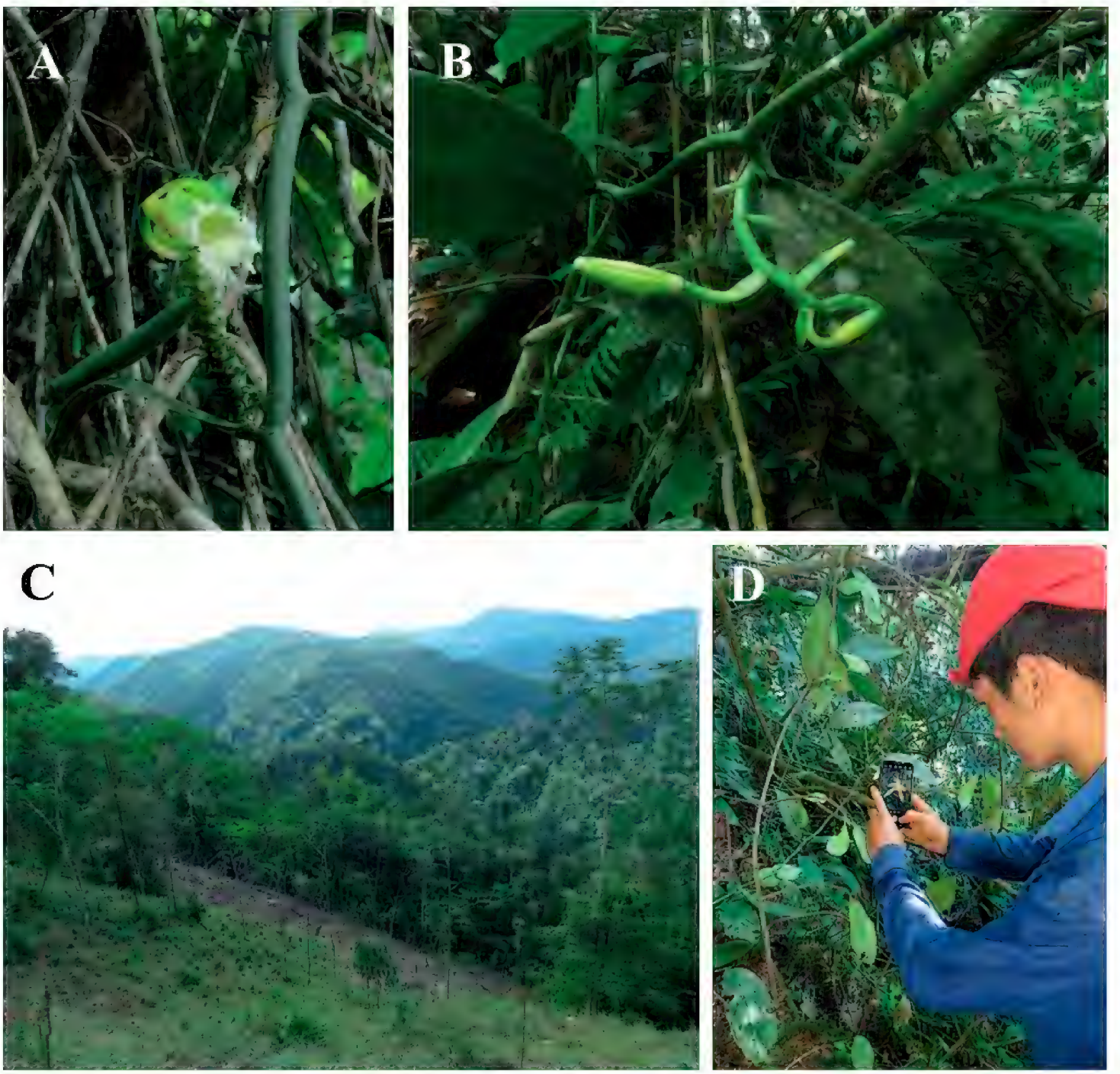


Figure 3. New records for *Vanilla* spp. from the Serranía de las Quinchas, Boyacá, Colombia **A.** Inflorescence of *V. karen-christianae* with flower and developing fruit **B.** Inflorescence of *V. dressleri* with buds **C.** View of rugged terrain where both species are found in secondary forest between plots opened for cacao cultivation on smallholder properties **D.** Community member (ENG-P) undertaking monitoring of *V. dressleri*.

the abaxial surface; when spread out 66–69 × 47–49 mm; blade subrhombic, margin entire, apex obtuse–rounded, very slightly notched, ca. 25–veined; central 3 veins in an elevated section from callus to apex, slightly warty at apex; ***penicillate callus*** retrorse, at ca. 30 mm from the lip base, made up by ca. 4–6, obdeltate, fimbriate scales, 4–6.5 × 2–3.5 mm. ***Column***, subterete, ca. 36–38 × 3.5–4.0 mm; densely pilose with short trichomes on mid 1/3 of the ventral surface, trichomes changing in colour from white basally to dark orange and ending abruptly, glabrous for 6 mm below the stigma. ***Stigma*** lateral lobes erect, obtusely deltate, lower apex acute, ca. 1.5 × 3 mm.subrhombic; rostellum, narrow, cuadrate, sharply convex 2 × 2.4 mm. ***Anther***, versatile, oval, obtuse 3 × 3 mm. ***Fruits*** subterete at base to subtrigonous at apex, 12–15 × 1–2 cm (3 months after pollination).

Vanilla dressleri can be distinguished from similar species, including the partially sympatric *V. cribbiana* and *V. rivasii*, as well as *V. ruiziana* and *V. weberbaueriana* known from the Amazon (Damián and Janovec 2018), by the lax inflorescence with patent bracts, and an entire lip with subrhombic blade. This record differs in morphological traits from the type description of *V. dressleri* in the following ways: it has a laxer inflorescence, with a longer rachis and more separated bracts; the lip coloring is less intense, lacking the prominent brownish colored veins of the type specimen; notably, the lip has an entire margin compared to the undulate, pleated margin described in the type specimen.

In total, fifteen different plants of *Vanilla dressleri* were found by ENG-P over an area of approximately 8 km^2 of secondary forest between plots opened for cacao cultivation on smallholder properties in Altazor (Fig. 3C). In this rugged terrain the plants ranged over elevations of between 400 and 950 m.a.s.l. Flowering occurs principally in March to April, with a less productive event in July, with only 1–4 inflorescences per plant.

Vanilla dressleri was first described for science in 2010 (Soto Arenas and Dressler 2010) and has only 21 records in 17 known occurrence localities. These are distributed from northern Costa Rica through Panama, and southwards through the Chocó biogeographic region on the Colombian and Ecuadorian pacific coast. Altitude distribution ranges between 20 and 950 m.a.s.l.. In Colombia, the species is known from the Chocó biogeographic region on the Pacific littoral. A single record from 1993 is located in the foothills of the Central Cordillera, to the west of the Magdalena River (Table 2; Fig. 4B).

The total Extent of Occurrence (EOO) calculated from GeoCAT for this species was 539,730 km^2. When only terrestrial areas below 1,500 m.a.s.l. were considered, this was reduced to 186,235 km^2. Of this area, 111,693 km^2 corresponds to humid tropical forest, with only 52,414 km^2 present in Colombia. The Area of Occupancy (AOO) for this species with such a small number of localities is 80 km^2.

IUCN Red List evaluation

In the countries in which these two species occur, average forest cover loss averaged 10% over the 25 years from 1990 to 2015 (Keenan et al. 2015). In Colombia,

Figure 4. Maps showing **A** global distribution of *Vanilla karen-christianae* **B** global distribution of *Vanilla dressleri* **C** distributions of V. *karen-christianae* and *V. dressleri* in Colombia with respect to Protected areas (A–J) covering humid tropical forest.

more than 50% of the remnant area of humid tropical forest in the Magdalena River watershed is at risk of deforestation (Etter et al. 2006), and the Mid-Magdalena region is considered a deforestation hotspot (Sanchez-Cuervo and Aide 2013). In the Chocó biogeographic region, areas of humid tropical forest are still relatively intact with 68% forest cover remaining, however deforestation due to illicit crops and alluvial mining has increased in recent years (Anaya et al. 2020).

Given the low current AOO and past and projected future decline in habitat, under the IUCN criterion B, Geographic range, both *Vanilla karen-christianae* and *V. dressleri* would be categorized as Endangered–EN: B2a,b(ii,iii,iv,v), with an AOO of less than 500 km^2, a severely fragmented population, and continuing decline inferred and projected in (ii) area of occupancy; (iii) area, extent and/or quality of habitat; (iv) number of locations or subpopulations; (v) number of mature individuals.

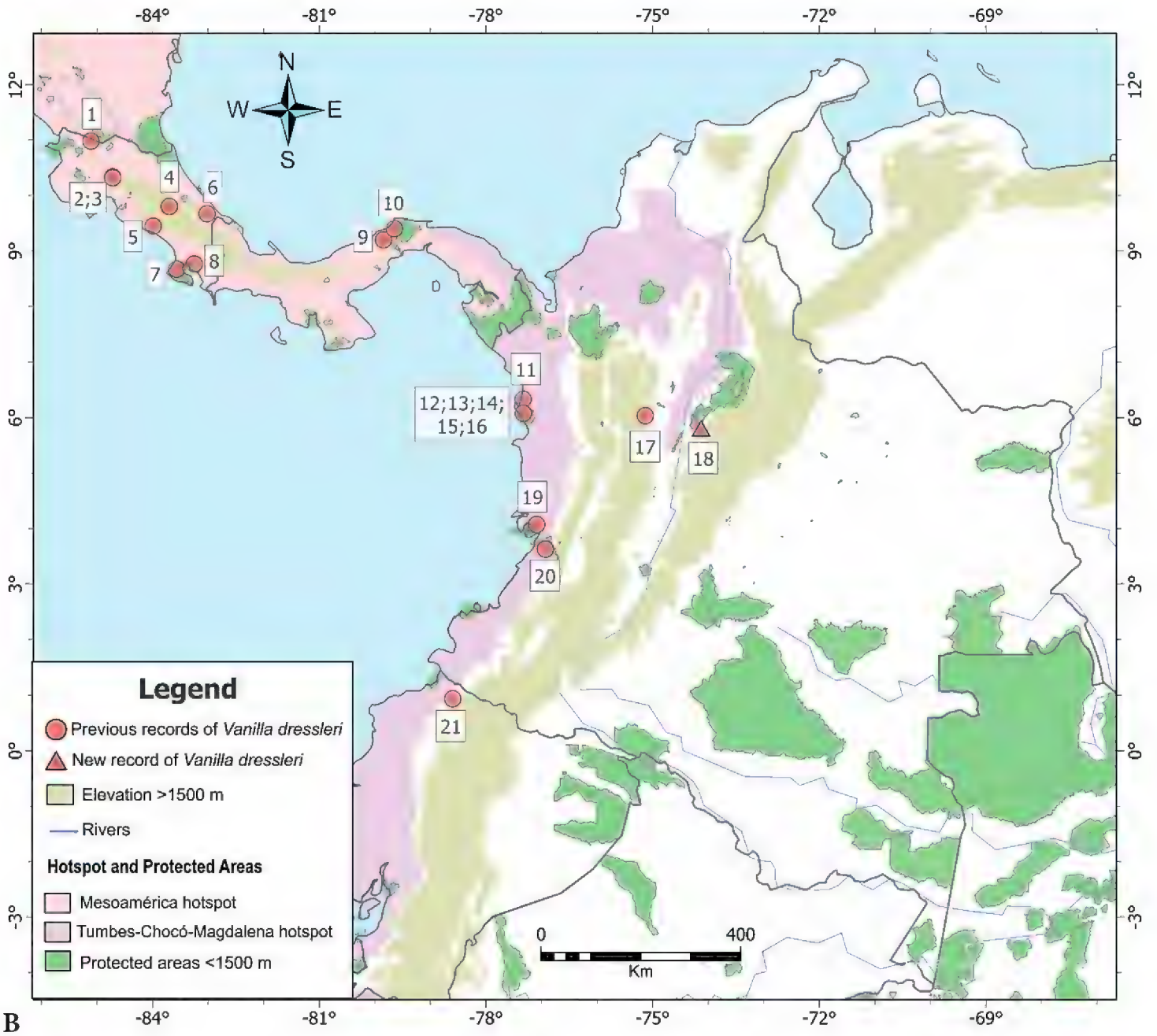
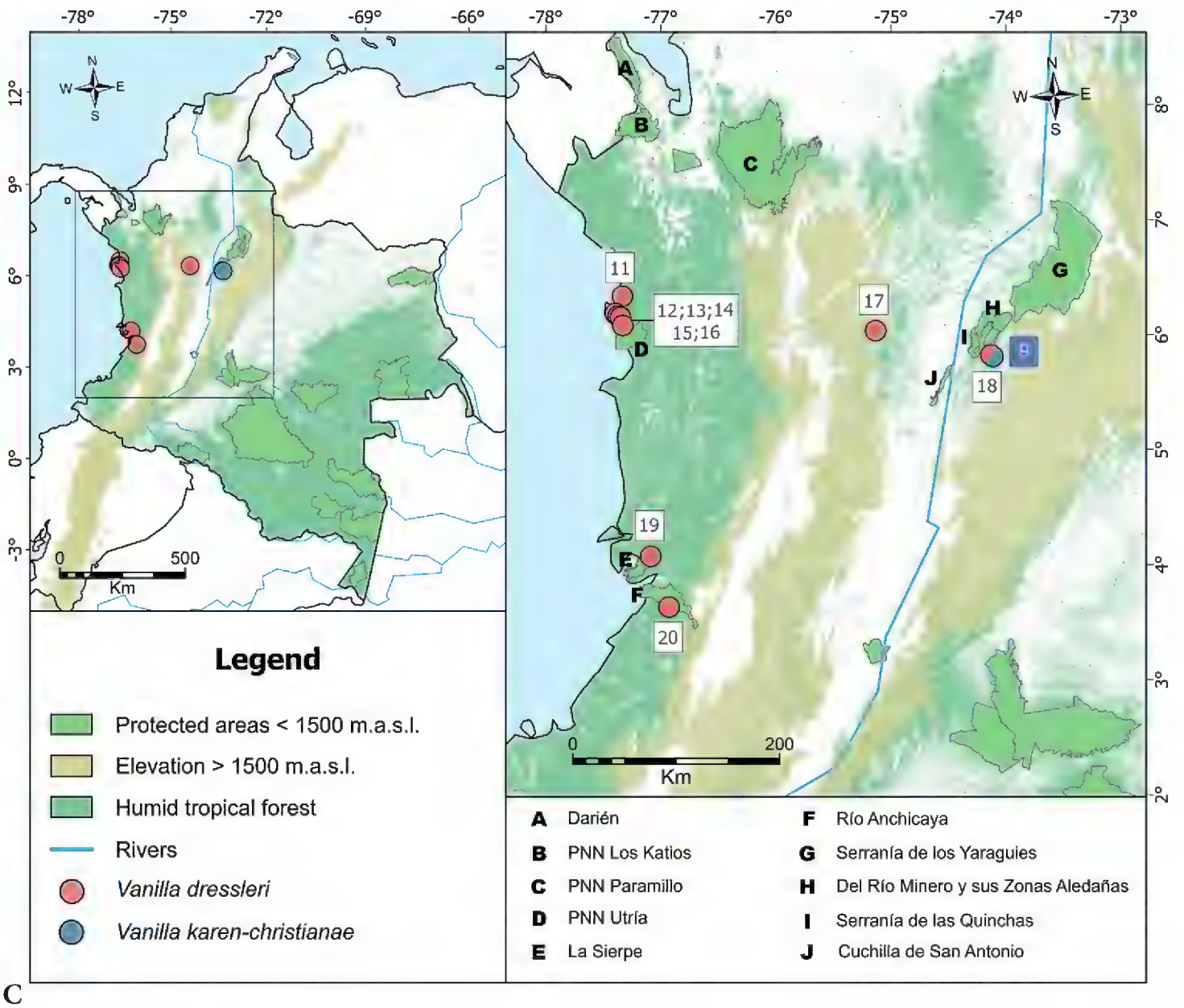


Figure 4. Continued.

Discussion

Species of the genus *Vanilla* (Orchidaceae) represent the crop wild relatives of natural vanilla and are a global priority for conservation actions (Flanagan et al. 2018). Nonetheless, their natural rarity in the wild, together with their infrequent flowering, has hindered the necessary taxonomic and species distribution studies for this economically important genus. Research approaches that encourage local community participation offer an important means to enhance capacity to further scientific research and conservation objectives in biodiverse countries and regions (Dickinson et al 2012; IPBES 2019). In a participatory scientific endeavour with local community members (Fig. 3D), we report the occurrence of two recently described species of *Vanilla* in the under-explored region of the Serranía de las Quinchas, Department of Boyacá, Colombia. These reports represent an important contribution to our understanding of *Vanilla* species distributions, strengthening the evidence base to develop species conservation and management strategies.



C

Figure 4. Continued.

Our findings represent the first report of *Vanilla karen-christianae* Karremans & P.Lehm. for Colombia, illuminating the trans–Andean connection between the previously known disjunct distributions of this species in Mesoamerica, and the Amazon basin. Recently, Chiron et al. (2021) proposed the synonymy of *V. karen-christianae* with *V. ensifolia* Rolfe (1892). The latter was described from imperfect material collected in the Andean region of Colombia (Cauca and Patia). In the characters for which data is available for *V. ensifolia*, our material clearly differs from the taxonomic description of *V. ensifolia* in the deeply emarginate, conspicuously trilobed lip compared with the entire, rounded lip described for *V. ensifolia*. Currently (2022-07-21), the World Checklist of Selected Plant Families (WCSP - https://wcsp.science.kew.org/), follows the consensus in the literature and considers the name *Vanilla ensifolia* to be a synonym of *V. odorata*.

The species *Vanilla dressleri* Soto Arenas was previously recorded in Mesoamerica and the Chocó biogeographic region on the Colombian and Ecuadorian pacific coast. This is the first report for this species to the east of the Magdalena River, thereby extending the species range within the Andean region. The distribution for

V. dressleri encompasses both the Tumbes–Chocó–Magdalena and the Mesoamerican biodiversity hotspots (Mittermeier et al. 2011).

Both species pertain to *Vanilla* subgenus *Xanata* Section *Xanata* Soto Arenas and Cribb 2010, and these reports bring the total number of *Vanilla* species in Colombia to 27, with 22 in the Section *Xanata*. This clade represents the secondary gene pool of the vanilla crop, and these new occurrences further highlight the importance of Colombia as a centre of diversity for vanilla crop wild relatives (Flanagan et al. 2018; Barona-Colmenares et al. 2019).

Despite relatively wide distributions, both *Vanilla karen-christianae* and *V. dressleri*, like many species in the genus, are naturally rare. These recently described species each have fewer than 25 occurrence reports in widely separated localities over their total distributions, with resulting Areas of Occupancy (AOO) of less than 100 km^2. The once continuous lowland humid forest cover from Central America through the Darién region and into northern South America is now severely fragmented, and decline continues in both the extent and quality of habitat (Mayaux et al. 2005; Sanchéz-Cuervo and Aide 2013; Keenan et al. 2015). Our preliminary conservation status evaluation following IUCN criteria indicates both species can be considered Endangered–EN, based on IUCN category B2a,b(ii,iii,iv,v).

Of the 11 *Vanilla* species within the Section *Xanata* now evaluated under the IUCN Red List criteria (IUCN 2022), ten are considered threatened, and one data deficient. This underlines the urgent need for conservation actions for these economically important wild plants at the international and national levels, in accordance with global policy (CBD 2022).

While IUCN Red List species conservation assessments are preferentially undertaken at a global level, conservation management plans are more commonly developed and implemented at a national or even regional scale. Despite vanilla crop wild relatives being a national conservation priority, no *Vanilla* species is listed as a conservation concern in Colombia (Ministerio de Ambiente y Desarrollo Sostenible and Universidad Nacional de Colombia 2015). Although neither species is endemic to the country, *Vanilla karen-christianae* is known from a single locality and *V. dressleri* from only six localities in the country. Data available for population size reveal a small number of individuals, with no evident recruitment of juvenile individuals. These observations would suggest that for the national Red List evaluation, both species would be categorized as Critically Endangered – CR based on IUCN Criterion C (Population size): C2a (i,ii), with fewer than 250 mature individuals in total registered, fewer than 50 (more than 90%) mature individuals in each subpopulation.

For conservation *in situ* it is essential that populations of *Vanilla* species are present within protected areas. All recorded occurrences for both *Vanilla dressleri* and *V. karen-christianae* fall outside Colombian protected areas (Fig. 4C). The distributions of both species correspond to the biomes of ´tropical humid zonobiome of the Magdalena River and Caribbean region´ and ´tropical humid zonobiome of the Pacific and Atrato´, which have only 5.8% and 2.7% protected area respectively (Forero-Medina and Joppa 2010).

Further botanical exploration for *Vanilla* species is strongly recommended within protected areas covering the humid tropical forest biome. Those protected areas of highest priority for *Vanilla* exploration include the National Nature Parks PNN Los Katios, in the Darién region, and PNN Paramillo in the central Andean cordillera. At the regional level, within the departments of Boyacá and Santander further exploration is needed with the Regional Forest Reserve Las Quinchas, as well as the Cuchilla de San Antonio, and the Regional Districts for Integrated Management of the Serranía de los Yariguies and Del Rio Minero y sus Zonas Aledañas (see Fig. 4C). Additionally, for *Vanilla dressleri*, we recommend further exploration along the Pacific coastal region, in the PNN Utría in the Chocó department and in the regional protected areas around Buenaventura in the Valle del Cauca department, including the National Forest Reserve of Río Anchicaya, and the Regional Nature Park La Sierpe.

Given the small size of these *Vanilla* populations, and the ease of vegetative propagation of these plants we also recommend the implementation of programs of population augmentation in existing occurrence localities, together with managed introduction into neighboring protected areas. The introduction of material from known populations into *ex situ* conservation germplasm banks is a priority, in order to complement *in situ* conservation, and also permit further bioprospecting of these valuable crop wild relatives (Flanagan et al. 2018). Currently, only three *Vanilla* species are contained in *ex situ* collections in Colombia – *Vanilla calyculata*, *V. planifolia* and *V. pompona* (Ministerio de Ambiente y Desarrollo Sostenible and Universidad Nacional de Colombia 2015).

In addition to conventional *in situ* and *ex situ* conservation approaches, the promotion of participatory, community-based *circa situm* conservation strategies is also recommended. *Circa situm* conservation refers to those actions carried out within the native geographical range of a species but outside natural habitats (Dawson et al. 2013). In the case of vanilla, such actions may include the establishment of community germplasm banks, as well as cultivation in agroforestry systems or home gardens (Flanagan and Mosquera-Espinosa 2016). *Circa situm* conservation of *Vanilla* aligns directly with international policy which recognizes that the active participation of indigenous people and local communities (IPLC) as essential for effective conservation, restoration, and sustainable use of orchid biodiversity, while simultaneously offering avenues for improving local livelihoods and wellbeing (IPBES 2019).

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